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Ogawa

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(54) **FUEL CELL MODULE**

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H01M 8/06	(2006.01)
H01M 8/12	(2006.01)
H01M 8/24	(2006.01)
H01L 35/30	(2006.01)

(52) **U.S. Cl.**
CPC ***H01M 8/04007*** (2013.01); ***H01L 35/30*** (2013.01); ***H01M 8/04067*** (2013.01); ***H01M 8/04738*** (2013.01); ***H01M 8/0618*** (2013.01); ***H01M 8/1206*** (2013.01); ***H01M 8/2425*** (2013.01); *H01M 8/04074* (2013.01); *Y02E 60/521* (2013.01); *Y02E 60/525* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,770,106 B1 8/2004 Okamoto et al.
2004/0038095 A1 2/2004 Kushibiki et al.
(Continued)

FOREIGN PATENT DOCUMENTS

EP 1 962 362 8/2008
JP 4-280484 10/1992
(Continued)

OTHER PUBLICATIONS

Japanese Office Action dated Aug. 19, 2014, Application No. 2011-229925; partial English translation included.
(Continued)

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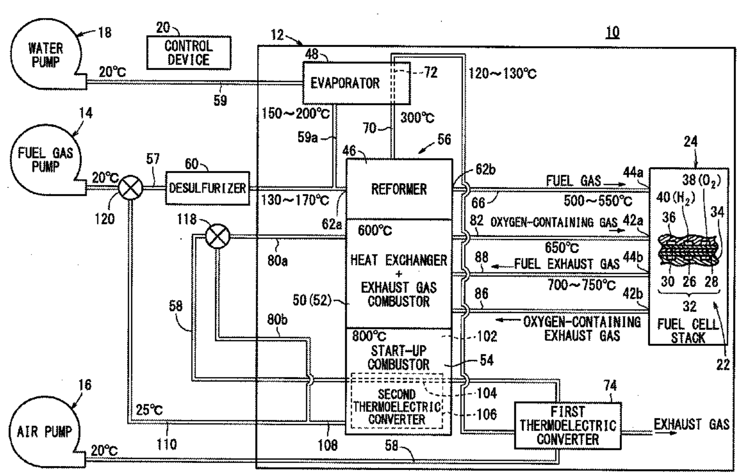
(57) **ABSTRACT**

A fuel cell module includes a fuel cell stack, a reformer for reforming a mixed gas of a raw fuel and water vapor, an evaporator for supplying water vapor to the reformer, and a heat exchanger for raising the temperature of the oxygen-containing gas by heat exchange with a combustion gas, and an exhaust gas combustor and a start-up combustor for producing the combustion gas. The fuel cell module includes a first thermoelectric converter and a second thermoelectric converter for performing thermoelectric conversion based on a temperature difference between the combustion gas and the oxygen-containing gas.

11 Claims, 13 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0089731	A1	4/2005	Ogiwara et al.
2005/0164051	A1	7/2005	Venkataraman et al.
2006/0107594	A1	5/2006	Kuwaba
2008/0008646	A1	1/2008	Kaye
2009/0263689	A1	10/2009	Homma
2011/0048484	A1	3/2011	Gao et al.
2011/0250513	A1	10/2011	Akikusa

FOREIGN PATENT DOCUMENTS

JP	6-103994	4/1994
JP	2000-251914	9/2000
JP	2003-086223	3/2003
JP	2003-229151	8/2003
JP	2004-087169	3/2004
JP	2004-319363	11/2004
JP	2005-166439	6/2005
JP	2006-143564	6/2006
JP	2007-042437	2/2007
JP	2007-311160	11/2007
JP	2008-218277	9/2008
JP	2008-251362	10/2008
JP	2010-218888	9/2010
WO	01/47800	7/2001
WO	2009/028169	3/2009

OTHER PUBLICATIONS

Japanese Office Action dated Sep. 24, 2014, Application No. 2011-229933; partial English translation included.

This application is co-pending with U.S. Appl. No. 14/241,734, filed Feb. 27, 2014.

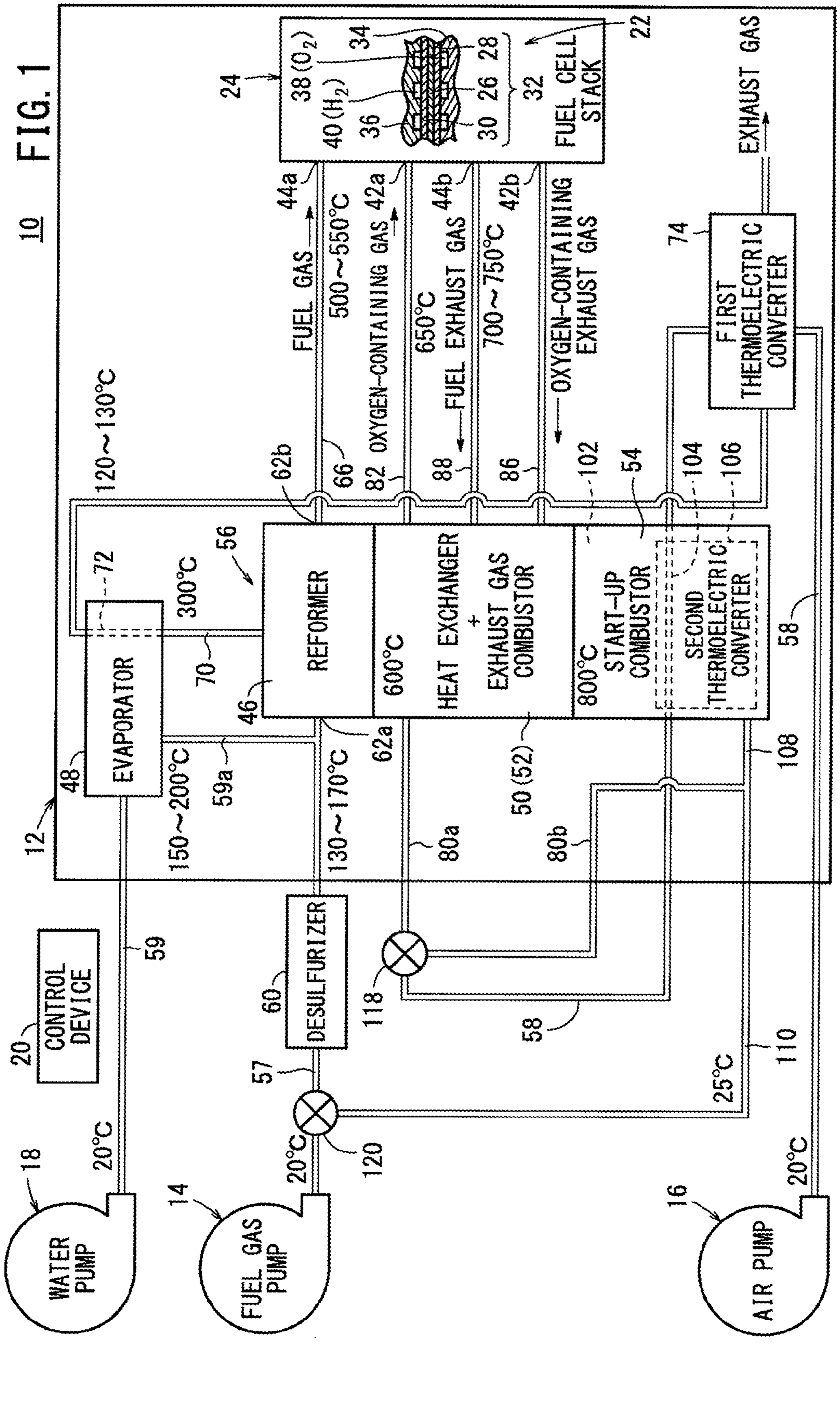

10
FUEL CELL STACK
REFORMER
HEAT EXCHANGER + EXHAUST GAS COMBUSTOR
START-UP COMBUSTOR
SECOND THERMOELECTRIC CONVERTER
FIRST THERMOELECTRIC CONVERTER
EVAPORATOR
DESULFURIZER
CONTROL DEVICE
WATER PUMP
FUEL GAS PUMP
AIR PUMP
FUEL GAS
OXYGEN-CONTAINING GAS
FUEL EXHAUST GAS
OXYGEN-CONTAINING EXHAUST GAS
EXHAUST GAS
$38(O_2)$
$40(H_2)$
500~550°C
650°C
700~750°C
120~130°C
300°C
600°C
800°C
150~200°C
130~170°C
20°C
25°C
12
14
16
18
20
22
24
26
28
30
32
34
36
42a
42b
44a
44b
46
48
50(52)
54
56
57
58
59
59a
60
62a
62b
66
70
72
74
80a
80b
82
86
88
102
104
106
108
110
118
120
FIG. 1

FIG. 2

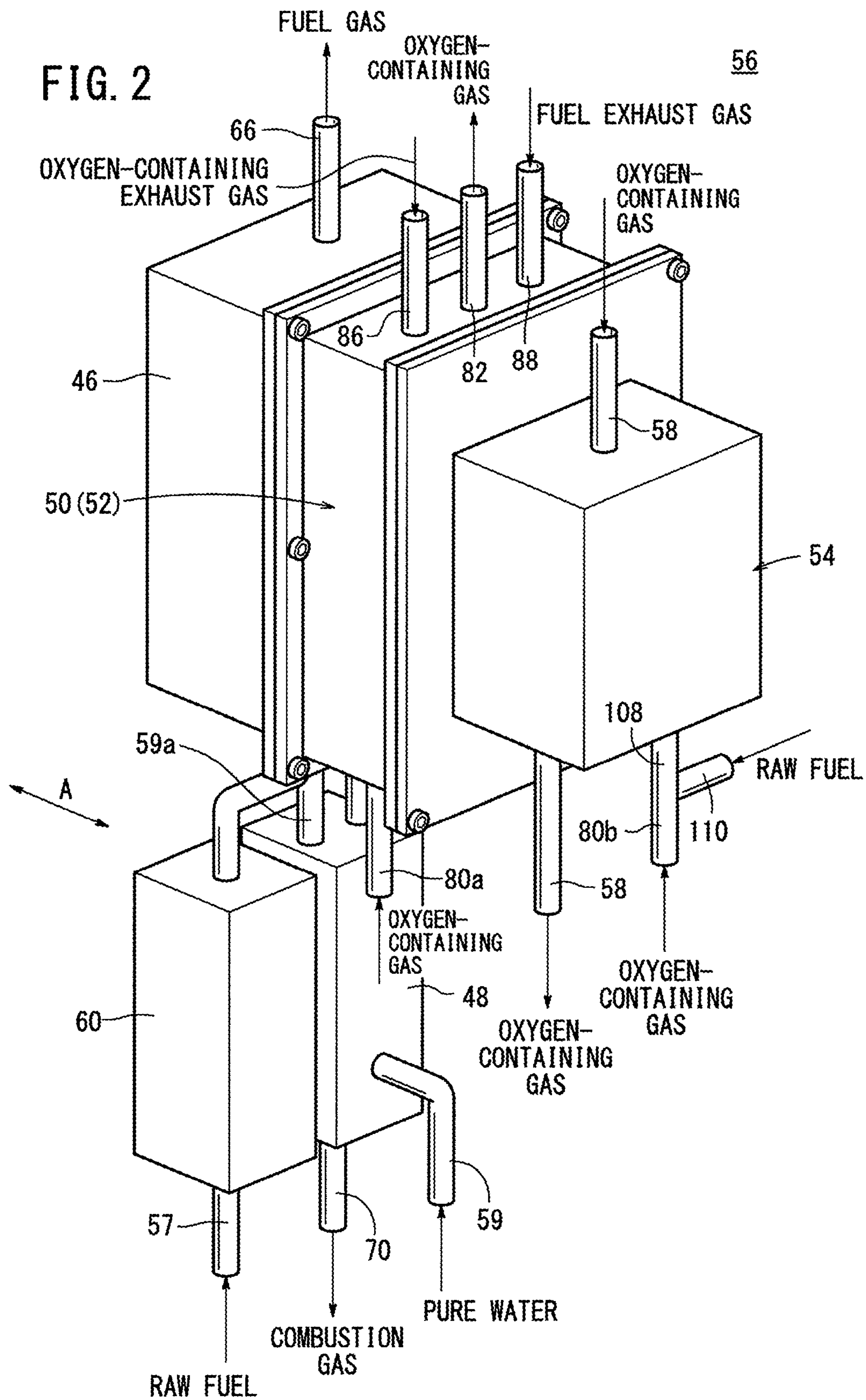
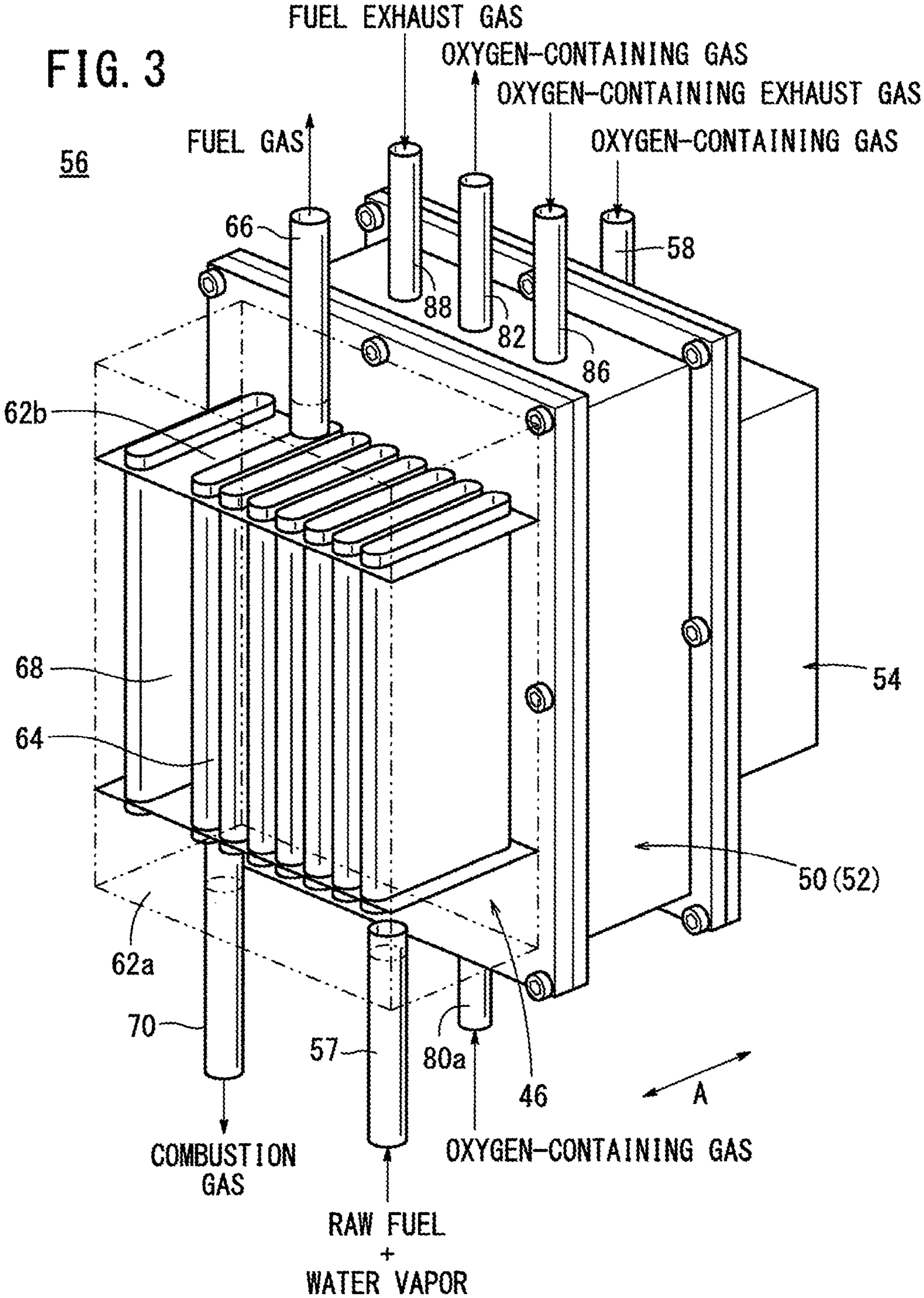

FUEL GAS
OXYGEN-CONTAINING GAS
56
FUEL EXHAUST GAS
66
OXYGEN-CONTAINING EXHAUST GAS
OXYGEN-CONTAINING GAS
86
82
88
46
58
50(52)
54
108
59a
RAW FUEL
A
80b
110
80a
58
OXYGEN-CONTAINING GAS
48
OXYGEN-CONTAINING GAS
OXYGEN-CONTAINING GAS
60
57
70
59
PURE WATER
COMBUSTION GAS
RAW FUEL

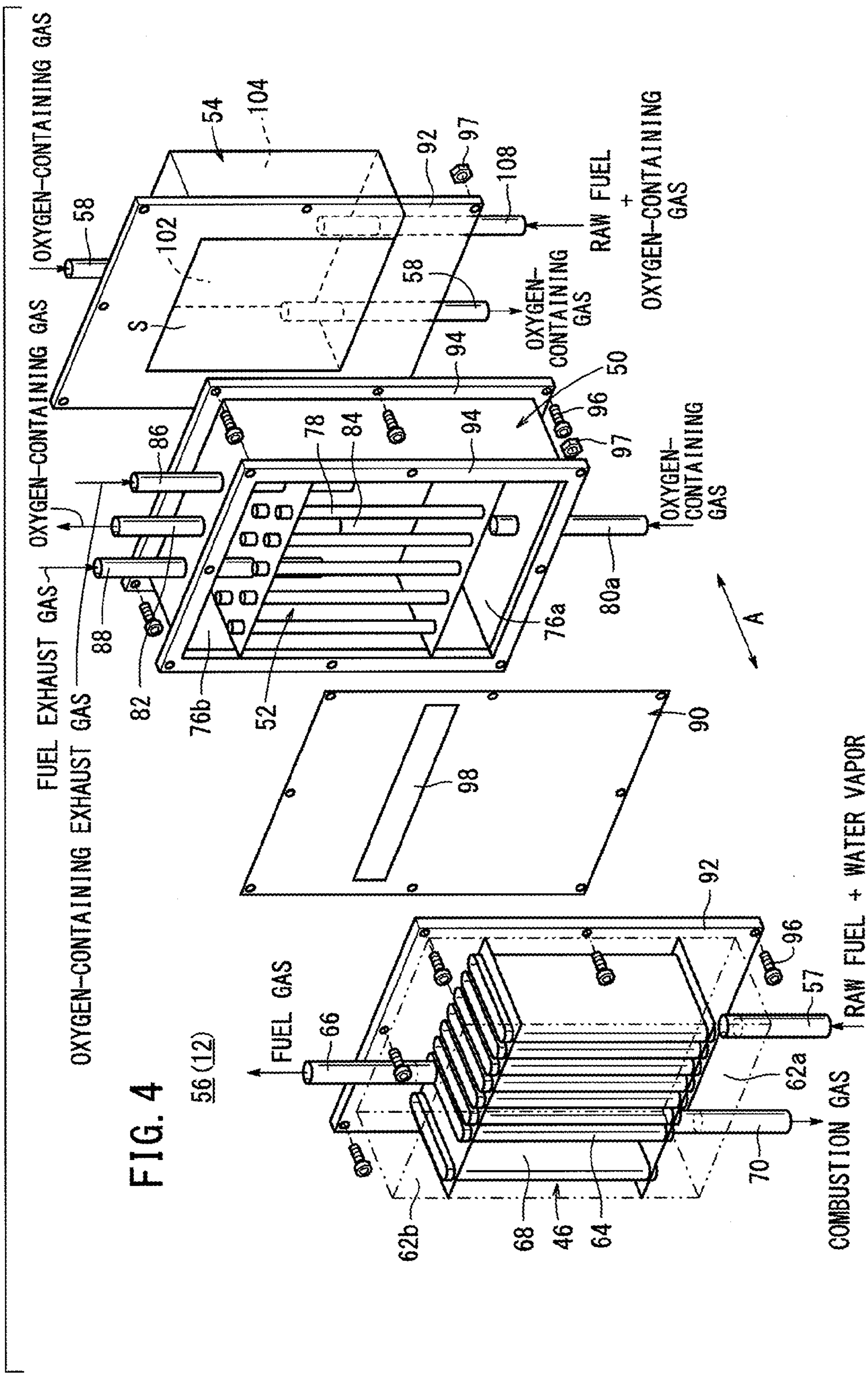
FIG. 3



FUEL EXHAUST GAS
OXYGEN-CONTAINING GAS
OXYGEN-CONTAINING EXHAUST GAS
OXYGEN-CONTAINING GAS
FUEL GAS
56
66
58
88
82
86
62b
68
64
54
50(52)
62a
70
57
80a
46
A
COMBUSTION GAS
OXYGEN-CONTAINING GAS
RAW FUEL
+
WATER VAPOR

FIG. 4

56 (12)



OXYGEN-CONTAINING GAS
58
54
104
102
S
92
97
108
RAW FUEL
+
OXYGEN-CONTAINING
GAS
OXYGEN-
CONTAINING
GAS
OXYGEN-CONTAINING GAS
94
50
96
86
78
84
FUEL EXHAUST GAS
OXYGEN-CONTAINING EXHAUST GAS
88
82
76b
52
76a
80a
A
90
98
FUEL GAS
66
92
96
57
RAW FUEL + WATER VAPOR
62a
70
COMBUSTION GAS
62b
68
46
64

FIG. 5

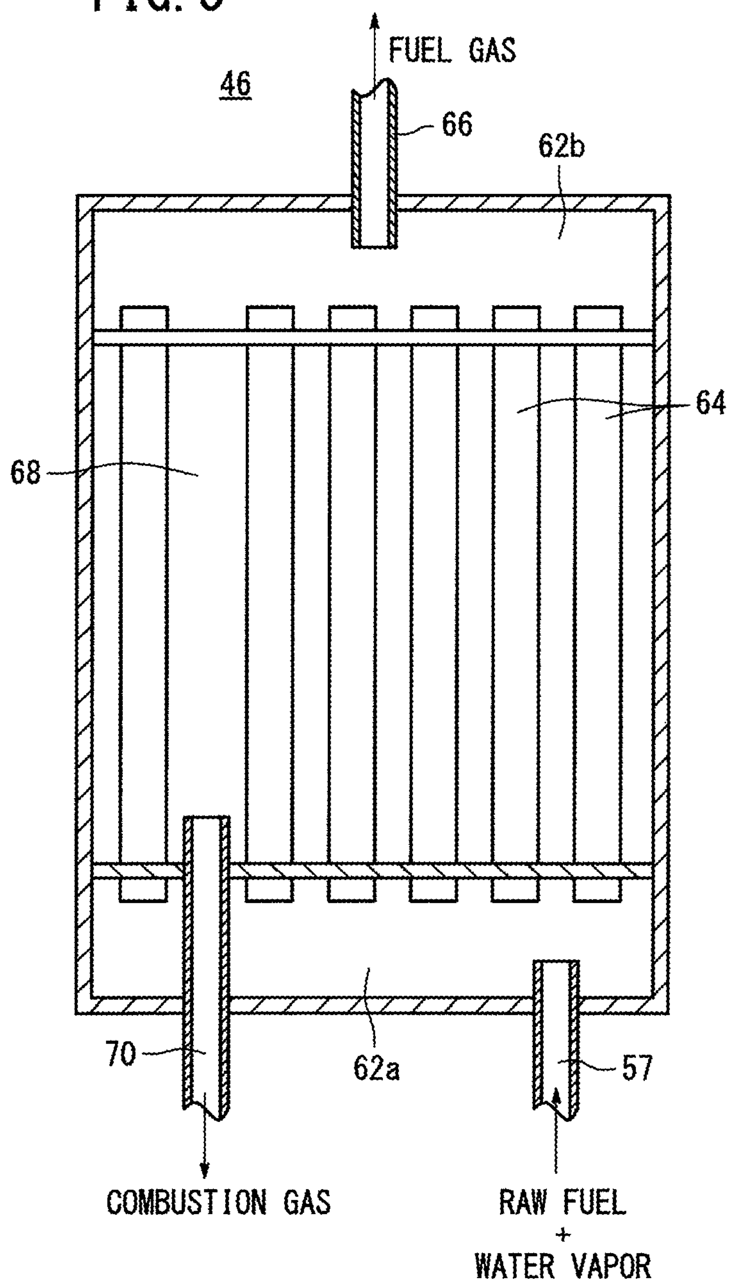

FUEL GAS
46
66
62b
64
68
70
62a
57
COMBUSTION GAS
RAW FUEL
+
WATER VAPOR

FIG. 6

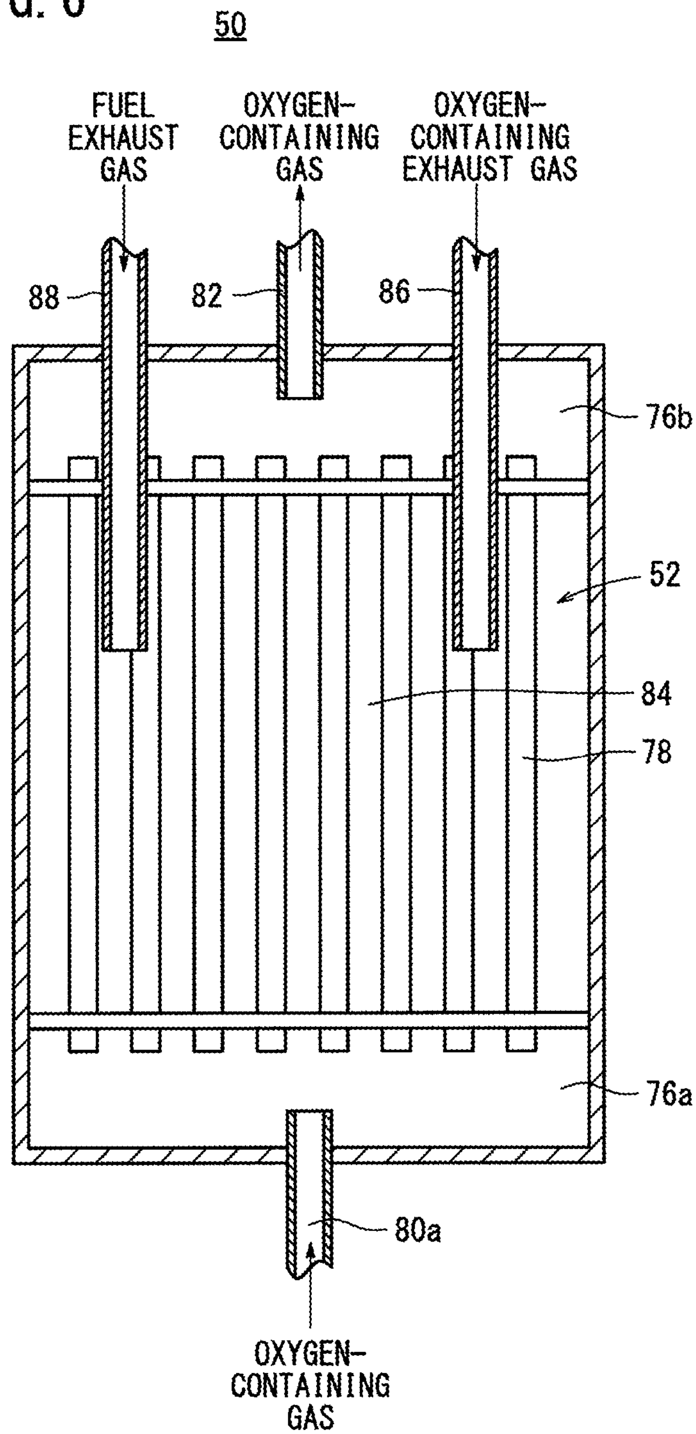

50
FUEL EXHAUST GAS
OXYGEN-CONTAINING GAS
OXYGEN-CONTAINING EXHAUST GAS
88
82
86
76b
52
84
78
76a
80a
OXYGEN-CONTAINING GAS

FIG. 7

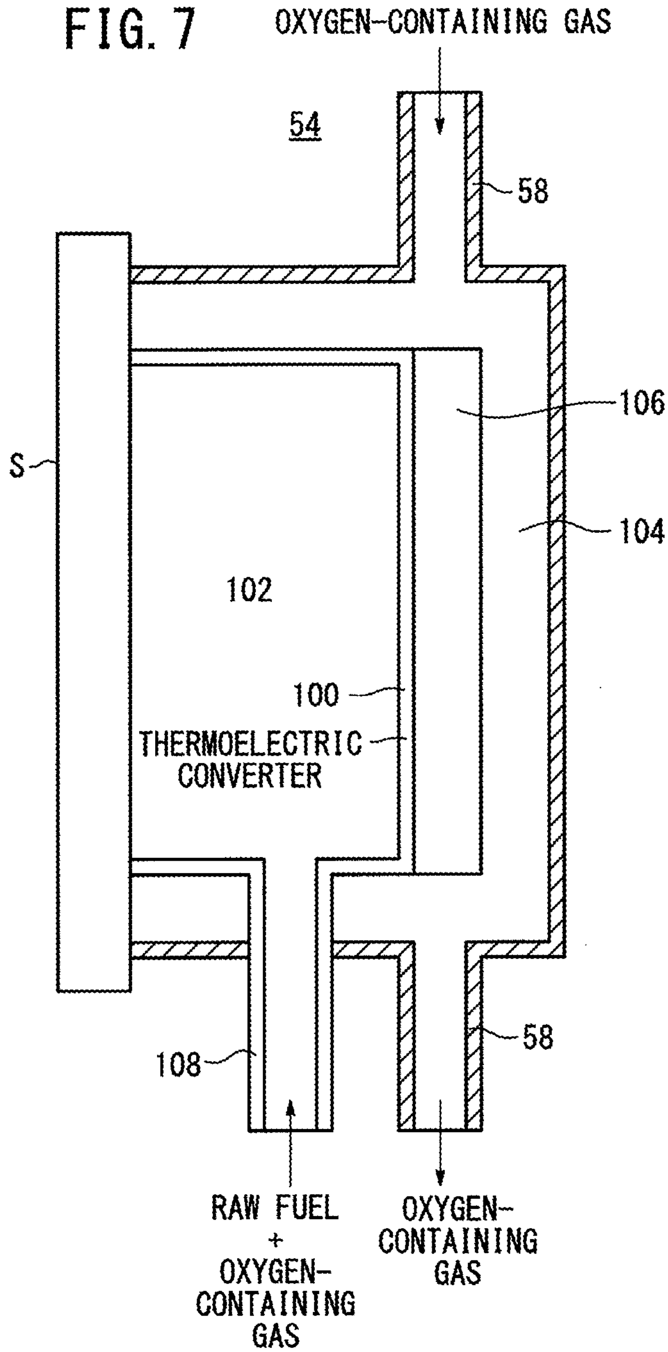

OXYGEN-CONTAINING GAS
54
58
106
S
104
102
100
THERMOELECTRIC
CONVERTER
108
58
RAW FUEL
+
OXYGEN-
CONTAINING
GAS
OXYGEN-
CONTAINING
GAS

FIG. 8

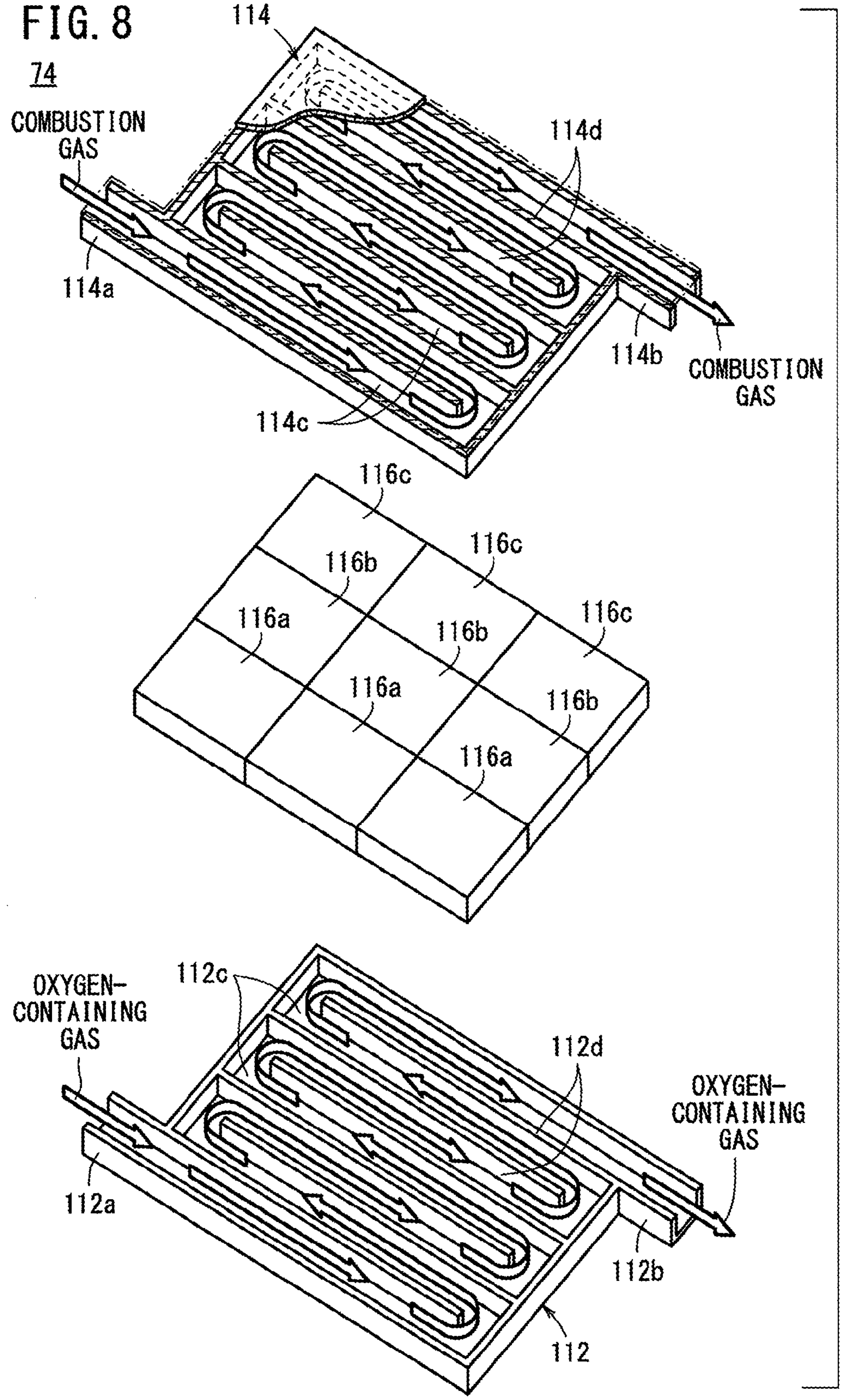

74
114
COMBUSTION GAS
114d
114a
114b
COMBUSTION GAS
114c
116c
116c
116b
116c
116a
116b
116a
116b
116a
OXYGEN-CONTAINING GAS
112c
112d
OXYGEN-CONTAINING GAS
112a
112b
112

FIG. 9

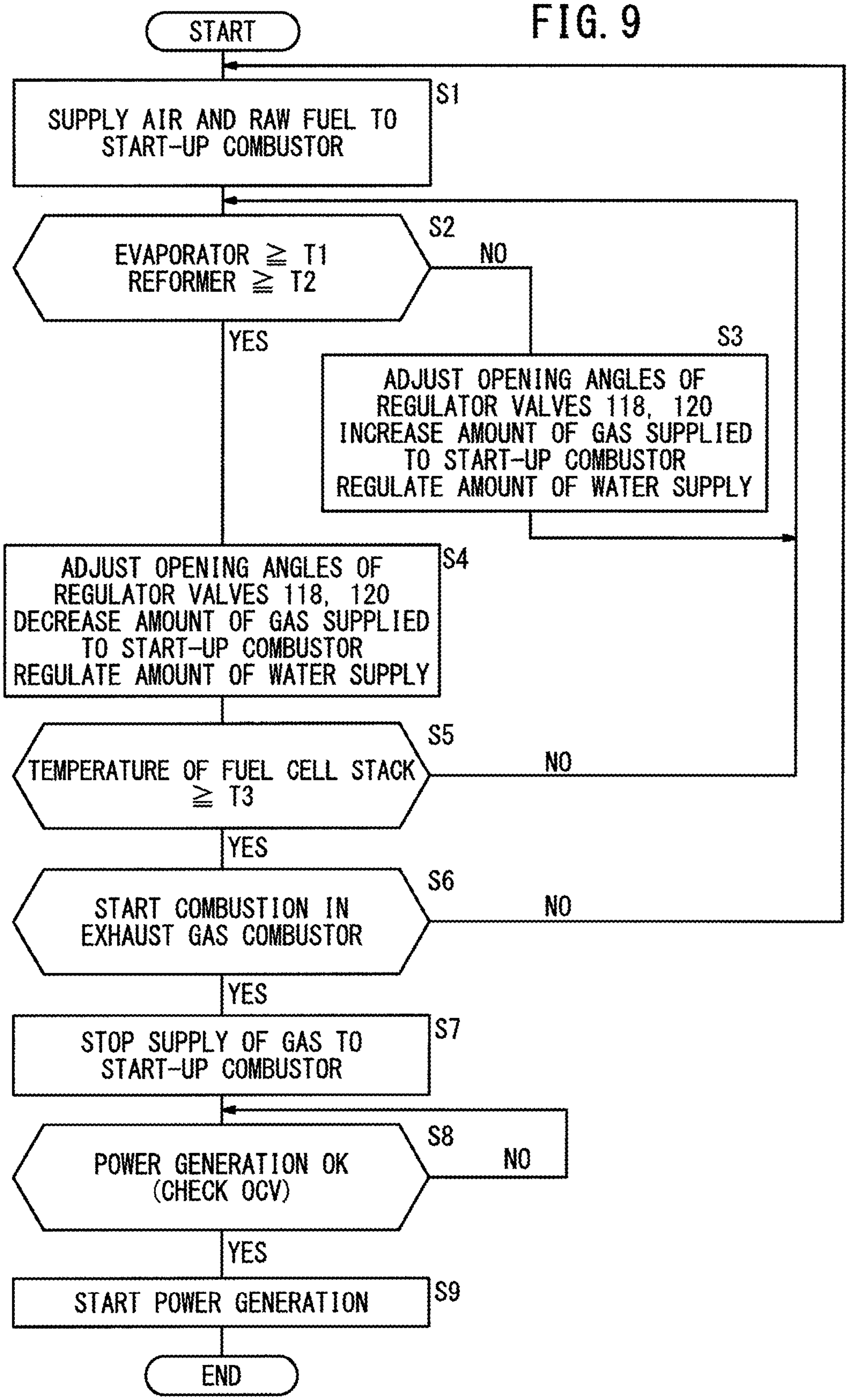

START
S1
SUPPLY AIR AND RAW FUEL TO START-UP COMBUSTOR
S2
EVAPORATOR ≧ T1
REFORMER ≧ T2
NO
YES
S3
ADJUST OPENING ANGLES OF REGULATOR VALVES 118, 120
INCREASE AMOUNT OF GAS SUPPLIED TO START-UP COMBUSTOR
REGULATE AMOUNT OF WATER SUPPLY
S4
ADJUST OPENING ANGLES OF REGULATOR VALVES 118, 120
DECREASE AMOUNT OF GAS SUPPLIED TO START-UP COMBUSTOR
REGULATE AMOUNT OF WATER SUPPLY
S5
TEMPERATURE OF FUEL CELL STACK ≧ T3
NO
YES
S6
START COMBUSTION IN EXHAUST GAS COMBUSTOR
NO
YES
S7
STOP SUPPLY OF GAS TO START-UP COMBUSTOR
S8
POWER GENERATION OK (CHECK OCV)
NO
YES
S9
START POWER GENERATION
END

FIG. 10

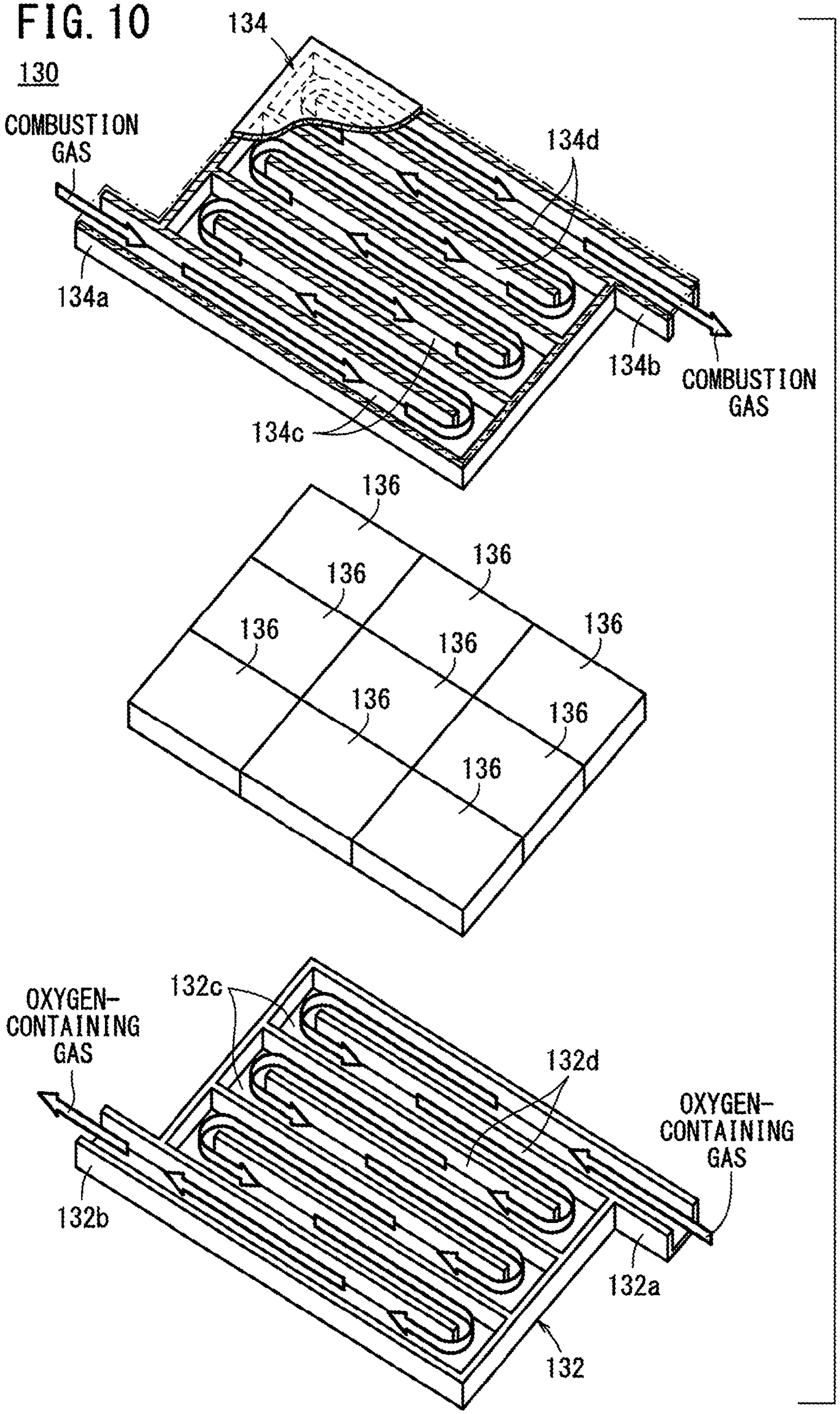

130
134
COMBUSTION GAS
134d
134a
134b
COMBUSTION GAS
134c
136
OXYGEN-CONTAINING GAS
132c
132d
OXYGEN-CONTAINING GAS
132b
132a
132

FIG. 11

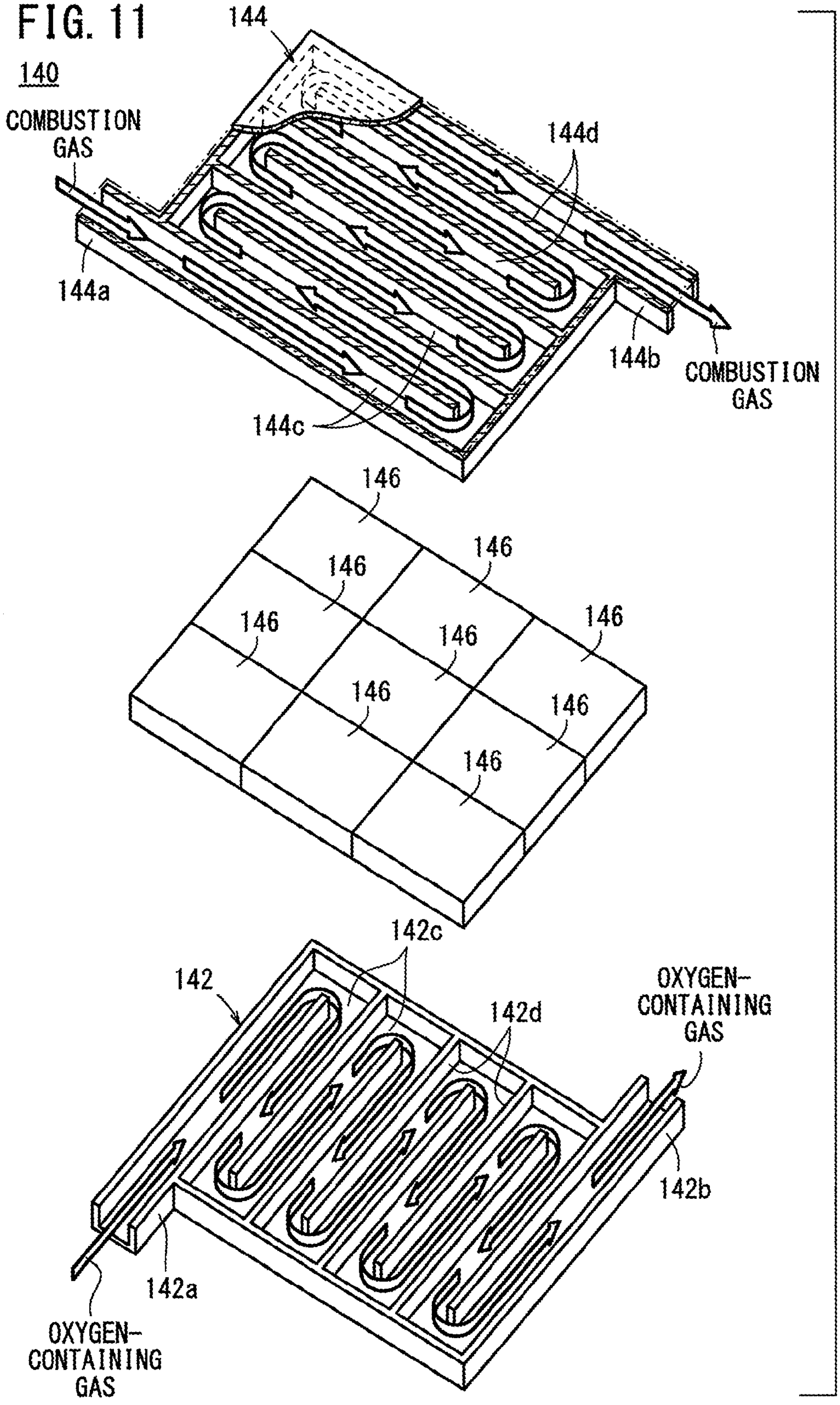

140
144
COMBUSTION GAS
144d
144a
144b
COMBUSTION GAS
144c
146
142c
142
OXYGEN-CONTAINING GAS
142d
142b
142a
OXYGEN-CONTAINING GAS

FIG. 12

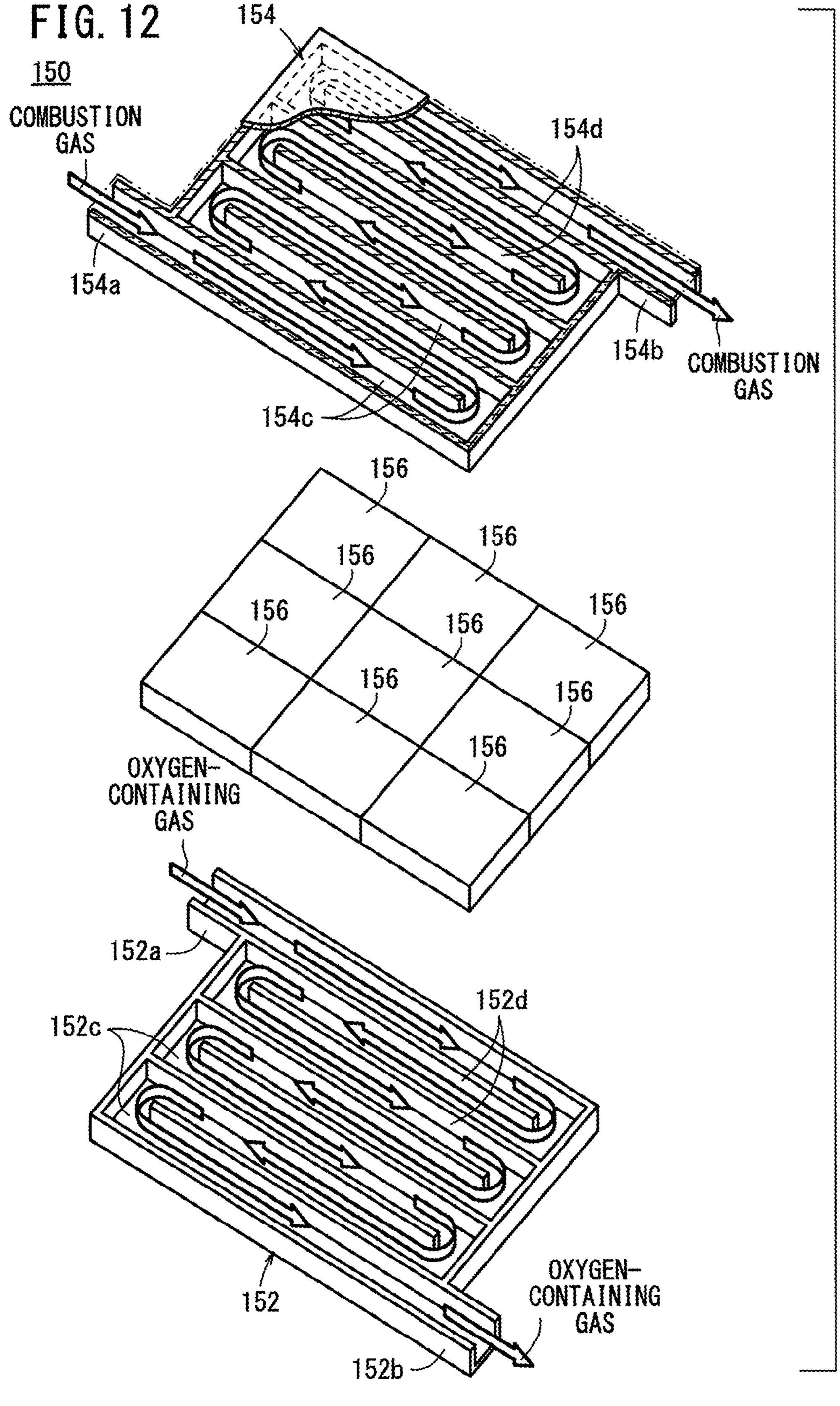
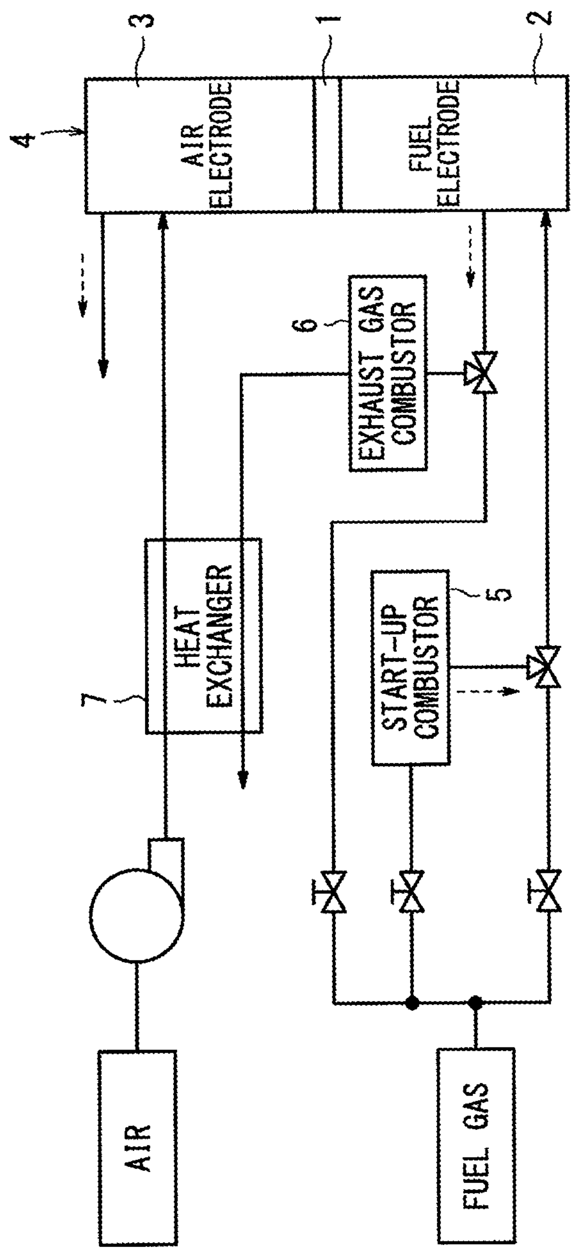

150
154
COMBUSTION GAS
154d
154a
154b
COMBUSTION GAS
154c
156
OXYGEN-CONTAINING GAS
152a
152d
152c
152
OXYGEN-CONTAINING GAS
152b

FIG. 13

PRIOR ART



FUEL CELL MODULE

TECHNICAL FIELD

The present invention relates to a fuel cell module including a fuel cell stack for generating electricity by electrochemical reactions of a fuel gas and an oxygen-containing gas.

BACKGROUND ART

Typically, a solid oxide fuel cell (SOFC) employs a solid electrolyte of ion-conductive oxide such as stabilized zirconia. The electrolyte is interposed between an anode and a cathode to form an electrolyte electrode assembly (MEA). The electrolyte electrode assembly is interposed between separators (bipolar plates). In use, generally, predetermined numbers of the electrolyte electrode assemblies and the separators are stacked together to form a fuel cell stack.

As a system including the fuel cell stack, for example, a fuel cell system disclosed in Japanese Laid-Open Patent Publication No. 2005-166439 (hereinafter referred to as the conventional technique **1**) is known. As shown in FIG. **13**, the fuel cell system uses a solid oxide fuel cell **4** having a solid electrolyte **1**, a fuel electrode **2** on one side of the solid electrolyte **1**, and an air electrode **3** on the other side of the solid electrolyte **1**. The air is supplied to the air electrode **3** as the oxygen-containing gas, and the fuel gas is supplied to the fuel electrode **2** for generating electricity by reaction of the fuel gas and the air.

In the fuel cell system, additionally, a start-up combustor **5**, an exhaust gas combustor **6**, and a heat exchanger **7** are provided. At the time of starting operation of the fuel cell system, the start-up combustor **5** reforms or imperfectly combusts the fuel gas supplied from the outside to supply the fuel gas to the fuel electrode **2** as a reducing gas. The exhaust gas combustor **6** combusts the off gas discharged form the fuel electrode **2**. The heat exchanger **7** heats the air by the heat generated in the exhaust gas combustor **6**.

According to the disclosure, in the structure, the large amount of unconsumed exhaust gas such as carbon monoxide produced in the fuel cell system at the time of starting operation of the fuel cell system can be reduced as much as possible, generation of heat stress due to the temperature difference can be prevented by heating both of the fuel electrode **2** and the air electrode **3**, and improvement in the durability of the fuel cell system is achieved. Further, both of the fuel electrode **2** and the air electrode **3** can be heated at the same time efficiently, and the time required for starting operation of the fuel cell system is reduced.

SUMMARY OF INVENTION

In the conventional technique **1**, the heat produced in the exhaust gas combustor **6** is supplied to the heat exchanger **7** to heat the air, and then, the heat is emitted to the outside. However, the heat emitted from the heat exchanger **7** has a considerably high temperature, and the heat energy is discharged wastefully. Further, due to the emission of the heat at the high temperature from the heat exchanger **7**, problems of waste heat occur disadvantageously.

The present invention has been made to solve the problems of this type, and an object of the present invention is to provide a fuel cell module which makes it possible to suppress heat energy losses suitably, facilitate thermally self-sustaining operation, and improve power generation efficiency.

The present invention relates to a fuel cell module including a fuel cell stack for generating electricity by electrochemical reactions of a fuel gas and an oxygen-containing gas, a reformer for reforming a mixed gas of water vapor and a raw fuel chiefly containing hydrocarbon to produce the fuel gas, and supplying the fuel gas to the fuel cell stack, an evaporator for evaporating water, and supplying water vapor to the reformer, a heat exchanger for raising a temperature of the oxygen-containing gas by heat exchange with a combustion gas, and supplying the oxygen-containing gas to the fuel cell stack, an exhaust gas combustor for combusting the fuel gas discharged from the fuel cell stack as a fuel exhaust gas and the oxygen-containing gas discharged from the fuel cell stack as an oxygen-containing exhaust gas to produce the combustion gas, and a start-up combustor for combusting the raw fuel and the oxygen-containing gas to produce the combustion gas.

The fuel cell module includes a thermoelectric converter for performing thermoelectric conversion based on a temperature difference between the combustion gas and the oxygen-containing gas.

In the present invention, the temperature difference between the combustion gas and the oxygen-containing gas, i.e., the heat energy can be collected as electrical energy. In particular, it becomes possible to improve the power generation efficiency without any losses in the start-up time. Further, since the temperature of the combustion gas is decreased, generation of waste heat is suppressed. Moreover, since the temperature of the oxygen-containing gas is increased, thermally self-sustaining operation is facilitated.

The combustion gas herein is a gas generated by the exhaust gas combustor and the start-up combustor. The combustion gas is a heating medium which can provide heat by performing heat exchange with a fluid to be heated (e.g., another gas). After heat energy is released from the combustion gas, the combustion gas is referred to as the exhaust gas.

Further, thermally self-sustaining operation herein means operation where the entire amount of heat quantity required for operating the fuel cell system is supplied within the fuel cell system, and where the operating temperature of the fuel cell system is maintained using only heat energy generated in the fuel cell system, without supplying additional heat from the outside.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram schematically showing a structure of a fuel cell system including a fuel cell module according to a first embodiment of the present invention;

FIG. **2** is a perspective view schematically showing FC (fuel cell) peripheral equipment of the fuel cell module;

FIG. **3** is a perspective view showing main components of the FC peripheral equipment;

FIG. **4** is an exploded perspective view showing main components of the FC peripheral equipment;

FIG. **5** is a partial cross sectional front view showing a reformer of the FC peripheral equipment;

FIG. **6** is a partial cross sectional front view showing a heat exchanger and an exhaust gas combustor of the FC peripheral equipment;

FIG. **7** is a partial cross sectional side view showing a start-up combustor of the FC peripheral equipment;

FIG. **8** is an exploded perspective view showing main components of a first thermoelectric converter of the fuel cell module;

FIG. **9** is a flow chart illustrating operation from start-up operation to steady operation of the fuel cell system;

FIG. **10** is an exploded perspective view showing main components of a thermoelectric converter of a fuel cell module according to a second embodiment of the present invention;

FIG. **11** is an exploded perspective view showing main components of a thermoelectric converter of a fuel cell module according to a third embodiment of the present invention;

FIG. **12** is an exploded perspective view showing main components of a thermoelectric converter of a fuel cell module according to a fourth embodiment of the present invention; and

FIG. **13** is a diagram schematically showing a fuel cell system disclosed in the conventional technique **1**.

DESCRIPTION OF EMBODIMENTS

A fuel cell system **10** shown in FIG. **1** includes a fuel cell module **12** according to a first embodiment of the present invention, and the fuel cell system **10** is used in various applications, including stationary and mobile applications. For example, the fuel cell system **10** is mounted on a vehicle.

The fuel cell system **10** includes the fuel cell module (SOFC module) **12** for generating electrical energy in power generation by electrochemical reactions of a fuel gas (e.g., a gas produced by mixing a hydrogen gas, methane, and carbon monoxide) and an oxygen-containing gas (air), a raw fuel supply apparatus (including a fuel gas pump) **14** for supplying a raw fuel (e.g., city gas) chiefly containing hydrocarbon to the fuel cell module **12**, an oxygen-containing gas supply apparatus (including an air pump) **16** for supplying the oxygen-containing gas to the fuel cell module **12**, a water supply apparatus (including a water pump) **18** for supplying water to the fuel cell module **12**, and a control device **20** for controlling the amount of electrical energy generated in the fuel cell module **12**.

The fuel cell module **12** includes a fuel cell stack **24** formed by stacking a plurality of solid oxide fuel cells **22** in a vertical direction (or in a horizontal direction). For example, the fuel cell **22** includes an electrolyte electrode assembly **32** (MEA). The electrolyte electrode assembly **32** includes a cathode **28**, an anode **30**, and an electrolyte **26** interposed between the cathode **28** and the anode **30**. For example, the electrolyte **26** is made of ion-conductive oxide such as stabilized zirconia.

A cathode side separator **34** and an anode side separator **36** are provided on both sides of the electrolyte electrode assembly **32**. An oxygen-containing gas flow field **38** for supplying an oxygen-containing gas to the cathode **28** is formed in the cathode side separator **34**, and a fuel gas flow field **40** for supplying a fuel gas to the anode **30** is formed in the anode side separator **36**. As the fuel cell **22**, various types of conventional SOFC can be adopted.

An oxygen-containing gas supply passage **42***a*, an oxygen-containing gas discharge passage **42***b*, a fuel gas supply passage **44***a*, and a fuel gas discharge passage **44***b* extend through the fuel cell stack **24**. The oxygen-containing gas supply passage **42***a* is connected to an inlet of each oxygen-containing gas flow field **38**, the oxygen-containing gas discharge passage **42***b* is connected to an outlet of each oxygen-containing gas flow field **38**, the fuel gas supply passage **44***a* is connected to an inlet of each fuel gas flow field **40**, and the fuel gas discharge passage **44***b* is connected to an outlet of each fuel gas flow field **40**.

The fuel cell module **12** includes a reformer **46** for reforming a mixed gas of a raw fuel and water vapor to produce a fuel gas supplied to the fuel cell stack **24**, an evaporator **48** for evaporating water and supplying water vapor to the reformer **46**, a heat exchanger **50** for raising the temperature of the oxygen-containing gas by heat exchange with a combustion gas and supplying the oxygen-containing gas to the fuel cell stack **24**, an exhaust gas combustor **52** for combusting the fuel gas discharged from the fuel cell stack **24** as a fuel exhaust gas and the oxygen-containing gas discharged from the fuel cell stack **24** as the oxygen-containing exhaust gas to produce the combustion gas, and a start-up combustor **54** for combusting the raw fuel and the oxygen-containing gas to produce the combustion gas.

Basically, the fuel cell module **12** includes the fuel cell stack **24** and FC (fuel cell) peripheral equipment **56**. The FC peripheral equipment **56** includes the reformer **46**, the evaporator **48**, the heat exchanger **50**, the exhaust gas combustor **52**, and the start-up combustor **54**. Further, as described later, no combustion gas pipes are provided between the reformer **46**, the heat exchanger **50**, the exhaust gas combustor **52**, and the start-up combustor **54**.

The raw fuel supply apparatus **14** has a raw fuel channel **57** for supplying the raw fuel to the reformer **46**. The oxygen-containing gas supply apparatus **16** has an oxygen-containing gas channel **58** for supplying the oxygen-containing gas from the heat exchanger **50** to the fuel cell stack **24**. The water supply apparatus **18** has a water channel **59** for supplying the water to the evaporator **48**.

In the FC peripheral equipment **56**, the exhaust gas combustor **52** is provided integrally in the heat exchanger **50**. The start-up combustor **54** is provided adjacent to one end of the heat exchanger **50**. The reformer **46** is provided adjacent to the other end of the heat exchanger **50**.

As shown in FIGS. **2** to **4**, the heat exchanger **50** is provided upright, and as described later, the oxygen-containing gas flows vertically upwardly. The reformer **46** is provided upright, and the reformed gas flows vertically upwardly. The start-up combustor **54** is directly attached to one side (one end) of the heat exchanger **50**, and the reformer **46** is directly attacked to the other side (the other end) of the heat exchanger **50**. The reformer **46**, the heat exchanger **50** (including the exhaust gas combustor **52**), and the start-up combustor **54** are stacked in a horizontal direction indicated by an arrow A.

As shown in FIG. **2**, the evaporator **48** and a desulfurizer **60** for removing sulfer compounds in the city gas (raw fuel) are provided below the heat exchanger **50** and the reformer **46**.

The reformer **46** is a preliminary reformer for reforming higher hydrocarbon (C_{2+}) such as ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}) in the city gas (raw fuel) to produce the fuel gas chiefly containing methane (CH_4), hydrogen, and CO by steam reforming. The operating temperature of the reformer **46** is several hundred ° C.

The operating temperature of the fuel cell **22** is high, at several hundred ° C. Methane in the fuel gas is reformed at the anode **30** to obtain hydrogen and CO, and the hydrogen and CO are supplied to the portion of the electrolyte **26** adjacent to the anode **30**.

As shown in FIG. **1**, the raw fuel supply apparatus **14** includes the desulfurizer **60**, and the desulfurizer **60** is provided in a middle of the raw fuel channel **57**. This raw fuel channel **57** is connected to a reform gas supply chamber **62***a* of the reformer **46**.

As shown in FIGS. **3** and **5**, the reform gas supply chamber **62***a* is connected to lower ends of a plurality of reforming pipes **64**, and a reform gas discharge chamber **62***b* is connected to upper ends of the reforming pipes **64**. The reform gas discharge chamber **62***b* is connected to one end of a fuel gas channel **66**, and the other end of the fuel gas channel **66** is connected to the fuel gas supply passage **44***a* of the fuel cell stack **24** (see FIG. **1**). Catalyst in the form of pellets (not shown) for inducing reforming reaction is filled in each of the reforming pipes **64**.

A heating space **68** is formed between the reforming pipes **64**. An end of a combustion gas channel **70** is opened to the heating space **68**, and as shown in FIG. **1**, a heating channel **72** of the evaporator **48** is provided in the middle of the combustion gas channel **70**. A first thermoelectric converter **74** is connected to the other end of the combustion gas channel **70**.

A water channel **59** of the water supply apparatus **18** is connected to the inlet of the evaporator **48**. The water flowing through the water channel **59** is heated by the combustion gas flowing along the heating channel **72**, and a water vapor is produced. One end of a water vapor channel **59***a* is connected to the outlet of the evaporator **48**, and the other end of the water vapor channel **59***a* is merged to the raw fuel channel **57** at a position downstream of the desulfurizer **60**.

As shown in FIGS. **4** and **6**, an oxygen-containing gas supply chamber **76***a* is provided on the lower side of the heat exchanger **50**, and an oxygen-containing gas discharge chamber **76***b* is provided on the upper side of the heat exchanger **50**. Both ends of a plurality of oxygen-containing gas pipes **78** are connected to the oxygen-containing gas supply chamber **76***a* and the oxygen-containing gas discharge chamber **76***b*.

One end of a first oxygen-containing gas supply channel **80***a* of the oxygen-containing gas channel **58** is provided in the oxygen-containing gas supply chamber **76***a*. One end of an oxygen-containing gas supply channel **82** is provided in the oxygen-containing gas discharge chamber **76***b*, and the other end of the oxygen-containing gas supply channel **82** is connected to the oxygen-containing gas supply passage **42***a* of the fuel cell stack **24** (see FIG. **1**).

A plurality of the oxygen-containing gas pipes **78** are placed in the space inside the heat exchanger **50**. Further, a combustion chamber **84** of the exhaust gas combustor **52** is formed inside the heat exchanger **50**. The combustion chamber **84** functions as a heat source for raising the temperature of the oxygen-containing gas by combustion reaction of the fuel gas (specifically, fuel exhaust gas) and the oxygen-containing gas (specifically, oxygen-containing exhaust gas).

An oxygen-containing exhaust gas channel **86** and a fuel exhaust gas channel **88** extend through the oxygen-containing gas discharge chamber **76***b*, and one end of the oxygen-containing exhaust gas channel **86** and one end of the fuel exhaust gas channel **88** are provided in the combustion chamber **84**. As shown in FIG. **1**, the other end of the oxygen-containing exhaust gas channel **86** is connected to the oxygen-containing gas discharge passage **42***b* of the fuel cell stack **24**, and the other end of the fuel exhaust gas channel **88** is connected to the fuel gas discharge passage **44***b* of the fuel cell stack **24**.

As shown in FIG. **4**, a wall plate (wall) **90** is provided between the reformer **46** and the heat exchanger **50**. The wall plate **90** is sandwiched between a flange **92** of the reformer **46** and a flange **94** of the heat exchanger **50**. These components are fixed together using a plurality of bolts **96** and nuts **97**. An opening (combustion gas channel) **98** is formed in the wall plate **90** for supplying a combustion gas produced in the combustion chamber **84** of the heat exchanger **50** to the heating space **68** of the reformer **46**.

As shown in FIG. **7**, a combustion chamber **102** is formed in the start-up combustor **54** through an internal casing **100**, and a cooling channel **104** for cooling the combustion chamber **102** is provided outside the internal casing **100**. The oxygen-containing gas channel **58** of the oxygen-containing gas supply apparatus **16** is connected to an upper portion and a lower portion of the cooling channel **104** (see FIG. **1**).

A rectangular flaming area S is designated in correspondence with the combustion chamber **84** of the exhaust gas combustor **52** (see FIG. **4**). A second thermoelectric converter **106** is provided between the combustion chamber **102** and the cooling channel **104**. A pre-mixing fuel channel **108** is connected to this combustion chamber **102**. As shown in FIG. **1**, a second oxygen-containing gas supply channel **80***b* and a raw fuel branch channel **110** branched from the raw fuel channel **57** are connected to the pre-mixing fuel channel **108**.

As shown in FIG. **4**, the flanges **92**, **94** of the start-up combustor **54** and the heat exchanger **50** are fixed together using a plurality of bolts **96** and nuts **97**.

As shown in FIG. **1**, the first thermoelectric converter **74** is provided in the oxygen-containing gas channel **58** at a position upstream of the heat exchanger **50**, more preferably, upstream of the cooling channel **104**. As shown in FIG. **8**, the first thermoelectric converter **74** includes a first channel member **112** as a passage of the oxygen-containing gas as a heated medium, a second channel member **114** as a passage of the combustion gas as a heating medium, and a plurality of thermoelectric conversion elements **116***a*, **116***b*, and **116***c* each having a different thermoelectric conversion temperature.

The first channel member **112** has a box shape, and includes a serpentine oxygen-containing gas channel **112***c* extending in a serpentine pattern between an oxygen-containing gas inlet **112***a* and an oxygen-containing gas outlet **112***b*. The serpentine oxygen-containing gas channel **112***c* is formed by partition plates **112***d* provided alternately in a zigzag pattern in the first channel member **112**.

The second channel member **114** has a box shape, and includes a serpentine combustion gas channel **114***c* extending in a serpentine pattern between a combustion gas inlet **114***a* and a combustion gas outlet **114***b*. The serpentine combustion gas channel **114***c* is formed by partition plates **114***d* provided alternately in a zigzag pattern in the second channel member **114**. The combustion gas in the serpentine combustion gas channel **114***c* and the oxygen-containing gas in the serpentine oxygen-containing gas channel **112***c* flow in parallel to each other.

Both ends of thermoelectric conversion elements **116***a*, **116***b*, and **116***c* are sandwiched between the first channel member **112** and the second channel member **114**, and the thermoelectric conversion elements **116***a*, **116***b*, and **116***c* are capable of generating an electromotive force by the temperature between these ends. A plurality of thermoelectric conversion elements **116***a* (though three thermoelectric conversion elements **116***a* are provided in FIG. **8**, the number of the thermoelectric conversion elements **116***a* can be determined arbitrarily. Likewise, the number of the thermoelectric conversion elements **116***b* and the thermoelectric conversion elements **116***c* can be determined arbitrarily.) are provided on the upstream side of the serpentine oxygen-containing gas channel **112***c* and the serpentine combustion gas channel **114***c*. The thermoelectric conversion elements **116***a* are hot temperature type thermoelectric conversion elements having a high thermoelectric conversion temperature.

The thermoelectric conversion elements **116***b* provided in the mid-portions of the serpentine oxygen-containing gas channel **112***c* and the serpentine combustion gas channel **114***c* are intermediate temperature type thermoelectric conversion elements having an intermediate thermoelectric conversion temperature. The thermoelectric conversion elements **116***c* provided on the downstream side of the serpentine oxygen-containing gas channel **112***c* and the serpentine combustion gas channel **114***c* are low temperature thermoelectric conversion elements having a low thermoelectric conversion temperature.

The second thermoelectric converter **106** has structure identical to the first thermoelectric converter **74**. In the second thermoelectric converter **106**, the oxygen-containing gas is supplied from the cooling channel **104**, and the combustion gas is supplied from the combustion chamber **102**. Though not shown, the oxygen-containing gas and the combustion gas flow in parallel to each other, and a plurality of thermoelectric conversion elements are provided between the serpentine oxygen-containing gas channel and the serpentine combustion gas channel.

As shown in FIG. **1**, the oxygen-containing gas supply apparatus **16** has an oxygen-containing gas regulator valve **118** for distributing the oxygen-containing gas from the oxygen-containing gas channel **58** to the heat exchanger **50** and the start-up combustor **54**, i.e., the first oxygen-containing gas supply channel **80***a* and the second oxygen-containing gas supply channel **80***b*.

The raw fuel supply apparatus **14** has a raw fuel regulator valve **120** for distributing the raw fuel to the reformer **46** and the start-up combustor **54**, i.e., the raw fuel channel **57** and the raw fuel branch channel **110**.

Next, operation of the fuel cell system **10** will be described below with reference to a flow chart of FIG. **9**.

At the time of starting operation of the fuel cell system **10**, the air (oxygen-containing gas) and the raw fuel are supplied to the start-up combustor **54** (step S**1**). Specifically, in the oxygen-containing gas supply apparatus **16**, the air is supplied to the oxygen-containing gas channel **58** by operation of the air pump. After the air flows through the first thermoelectric converter **74**, the air flows into the cooling channel **104** of the start-up combustor **54** (this operation will be described later). Further, the air is supplied from the second oxygen-containing gas supply channel **80***b* to the pre-mixing fuel channel **108** by operation of adjusting the opening angle of the oxygen-containing gas regulator valve **118**.

In the raw fuel supply apparatus **14**, raw fuel such as the city gas (containing CH_4, C_2H_6, C_3H_8, C_4H_{10}) is supplied to the raw fuel channel **57** by operation of the fuel gas pump. The raw fuel flows into the raw fuel branch channel **110** by operation of adjusting the opening angle of the raw fuel regulator valve **120**. This raw fuel is supplied to the pre-mixing fuel channel **108**, and mixed with the air. Further, the raw fuel is supplied to the combustion chamber **102** in the start-up combustor **54**.

Therefore, the mixed gas of the raw fuel and the air is supplied into the combustion chamber **102**, and the mixed gas is ignited to start combustion. Thus, as shown in FIG. **4**, since the heat exchanger **50** is directly connected to the start-up combustor **54**, the combustion gas is supplied to the combustion chamber **84** of the exhaust gas combustor **52** from the flaming area S of the start-up combustor **54**.

The combustion gas supplied to the combustion chamber **84** heats the heat exchanger **50**, and the combustion gas moves to the heating space **68** of the reformer **46** through the opening **98** formed in the wall plate **90**. Thus, the reformer **46** is heated. The combustion gas channel **70** is opened to the heating space **68**, and the combustion gas channel **70** is connected to the heating channel **72** of the evaporator **48**. In the structure, after the combustion gas heats the evaporator **48**, the combustion gas is supplied to the first thermoelectric converter **74**.

As shown in FIG. **8**, in the first thermoelectric converter **74**, the oxygen-containing gas as the external air is supplied from the oxygen-containing gas inlet **112***a* of the first channel member **112** to the serpentine oxygen-containing gas channel **112***c*, and the combustion gas is supplied from the combustion gas inlet **114***a* of the second channel member **114** to the serpentine combustion gas channel **114***c*. Thus, temperature differences occur between both ends of the thermoelectric conversion elements **116***a*, **116***b*, and **116***c* between the serpentine oxygen-containing gas channel **112***c* and the serpentine combustion gas channel **114***c*, and the heat energy is collected as electrical energy.

In the second thermoelectric converter **106**, the oxygen-containing gas is supplied from the cooling channel **104**, and the combustion gas is supplied from the combustion chamber **102**. Thus, as in the case of the first thermoelectric converter **74**, temperature differences occur between both ends of thermoelectric conversion elements (not shown), and the heat energy is collected as electrical energy.

Then, the control proceeds to step S**2** to determine whether or not the temperature of the evaporator **48** is a predetermined temperature T**1** or more and the temperature of the reformer **46** is a predetermined temperature T**2** or more. For example, the predetermined temperature T**1** is 150° C., and for example, the predetermined temperature T**2** is 550° C. If the temperature of the evaporator **48** is less than the predetermined temperature T**1** or the temperature of the reformer **46** is less than the predetermined temperature T**2**, the control proceeds to step S**3** (NO in step S**2**).

In step S**3**, the opening angle of the oxygen-containing gas regulator valve **118** is adjusted, and the amount of the air supplied to the second oxygen-containing gas supply channel **80***b* is increased. Further, the opening angle of the raw fuel regulator valve **120** is adjusted, and the amount of the raw fuel supplied to the raw fuel branch channel **110** is increased. Thus, the combustion rate in the start-up combustor **54** is increased, and the amount of the generated heat energy is increased. In the water supply apparatus **18**, the amount of water supplied to the evaporator **48** is regulated.

If it is determined that the temperature of the evaporator **48** is the predetermined temperature T**1** or more and the temperature of the reformer **46** is the predetermined temperature T**2** or more (YES in step S**2**), the control proceeds to step S**4**. In step S**4**, the opening angle of the oxygen-containing gas regulator valve **118** is adjusted to reduce the amount of the air supplied to the second oxygen-containing gas supply channel **80***b*. Further, the opening angle of the raw fuel regulator valve **120** is adjusted to reduce the amount of the raw fuel supplied to the raw fuel branch channel **110**. Thus, the combustion rate in the start-up combustor **54** becomes low, and the amount of the generated heat energy is decreased. In the water supply apparatus **18**, the amount of water supplied to the evaporator **48** is regulated.

Thus, in the oxygen-containing gas supply apparatus **16**, the flow rate of the air supplied to the first oxygen-containing gas supply channel **80***a* is increased by the oxygen-containing gas regulator valve **118**, and the air flows into the oxygen-containing gas supply chamber **76***a* of the heat exchanger **50**.

As shown in FIG. **6**, after the air flows into the oxygen-containing gas supply chamber **76***a*, the air is heated by the combustion gas supplied into the combustion chamber (heat exchange between the air and the combustion gas occurs) while the air is moving from the lower ends to the upper ends of the oxygen-containing gas pipes **78**. The heated air is supplied to the oxygen-containing gas discharge chamber **76***b* temporarily, and then, the air is supplied through the oxygen-containing gas supply channel **82** to the oxygen-containing gas supply passage **42***a* of the fuel cell stack **24** (see FIG. **1**).

In the fuel cell stack **24**, after the heated air flows through the oxygen-containing gas flow field **38**, the air is discharged from the oxygen-containing gas discharge passage **42***b* into the oxygen-containing exhaust gas channel **86**. As shown in FIG. **6**, since the oxygen-containing exhaust gas channel **86** is opened to the combustion chamber **84** of the exhaust gas combustor **52**, the air is supplied into the combustion chamber **84**.

Further, in the raw fuel supply apparatus **14**, as shown in FIG. **1**, the flow rate of the raw fuel supplied to the raw fuel channel **57** to the desulfurizer **60** is increased by the raw fuel regulator valve **120**. After sulfur is removed from the raw fuel by the desulfurizer **60**, the raw fuel flows through the raw fuel channel **57**, and the raw fuel is supplied to the reform gas supply chamber **62***a* of the reformer **46**. After the water supplied from the water supply apparatus **18** to the water channel **59** is evaporated by the evaporator **48**, the water flows through the raw fuel channel **57** from the water vapor channel **59***a*, and the water is supplied to the reform gas supply chamber **62***a*.

As shown in FIG. **5**, the mixed gas of the raw fuel and the water vapor supplied to the reform gas supply chamber **62***a* moves through the lower ends to the upper ends of the reforming pipes **64**. In the meanwhile, the mixed gas is heated by the combustion gas supplied into the heating space **68**, and steam reforming is induced by the catalyst in the form of pellets. Reforming reaction occur by removal of hydrocarbon of C_{2+} to produce a reformed gas chiefly containing methane. The reformed gas is supplied to the reform gas discharge chamber **62***b* temporarily as a heated fuel gas, and then, the reformed gas is supplied to the fuel gas supply passage **44***a* of the fuel cell stack **24** through the fuel gas channel **66** (see FIG. **1**).

In the fuel cell stack **24**, after the heated fuel gas flows through the fuel gas flow field **40**, the fuel gas is discharged from the fuel gas discharge passage **44***b* to the fuel exhaust gas channel **88**. As shown in FIG. **6**, since the fuel exhaust gas channel **88** is opened to the combustion chamber **84** of the exhaust gas combustor **52**, the fuel gas flows into the combustion chamber **84**.

As described above, heated air and the heated fuel gas flow through the fuel cell stack **24** to raise the temperature of the fuel cell stack **24**. If it is determined that the temperature of the fuel cell stack **24** is a predetermined temperature T**3** (e.g., 650° C.) or more (YES in step S**5**), the control proceeds to step S**6**. In step S**6**, it is determined whether or not combustion is started in the exhaust gas combustor **52**.

As shown in FIG. **6**, the air is supplied to the combustion chamber **84** of the exhaust gas combustor **52** through the oxygen-containing exhaust gas channel **86**, and the fuel gas is supplied to the combustion chamber **84** through the fuel exhaust gas channel **88**. Therefore, by heating operation of the start-up combustor **54**, when the temperature in the exhaust gas combustor **52** exceeds the self-ignition temperature of the fuel gas, combustion by the air and the fuel gas is started in the combustion chamber **84** (YES in step S**6**).

When combustion in the exhaust gas combustor **52** is started, the control proceeds to step S**7** for adjusting the opening angle of the oxygen-containing gas regulator valve **118** and the opening angle of the raw fuel regulator valve **120**, and the supply of the air and the raw fuel to the start-up combustor **54** is stopped.

Then, the control proceeds to step S**8** for determining whether or not power generation can be performed in the fuel cell stack **24**. Specifically, OCV (open-circuit voltage) of the fuel cell **22** is measured, and when the OCV reaches a predetermined value, it is determined that power generation can be performed in the fuel cell stack **24** (YES in step S**8**). Thus, power generation is started in the fuel cell stack **24** (step S**9**).

During power generation of the fuel cell stack **24**, in the same manner as in the case of the start-up operation, the air flows through the oxygen-containing gas flow field **38**, and the fuel gas flows through the fuel gas flow field **40**. Therefore, the air is supplied to the cathode **28** of each fuel cell **22**, and the fuel gas is supplied to the anode **30** of each fuel cell **22** to induce chemical reactions at the cathode **28** and the anode **30** for generating electricity.

The air partially consumed in the reaction (containing unconsumed air) is discharged as oxygen-containing exhaust gas to the oxygen-containing exhaust gas channel **86**. Further, the fuel gas partially consumed in the reaction (containing unconsumed fuel gas) is discharged as the fuel exhaust gas to the fuel exhaust gas channel **88**. The oxygen-containing exhaust gas and the fuel exhaust gas are supplied to the exhaust gas combustor **52**, and combusted in the exhaust gas combustor **52**.

In the first embodiment, the fuel cell module **12** includes the first thermoelectric converter **74** and the second thermoelectric converter **106** for performing thermoelectric conversion based on the temperature difference between the oxygen-containing gas and the combustion gas. As shown in FIG. **8**, the first thermoelectric converter **74** includes the first channel member **112** as a passage of the oxygen-containing gas as a heated medium, the second channel member **114** as a passage of the combustion gas as a heating medium, and the plurality of thermoelectric conversion elements **116***a*, **116***b*, and **116***c* each having a different thermoelectric conversion temperature provided between the first channel member **112** and the second channel member **114**.

In the structure, the first thermoelectric converter **74** and the second thermoelectric converter **106** can collect electrical energy based on the temperature difference between the combustion gas and the oxygen-containing gas. That is, the heat energy can be collected as electrical energy. In particular, it becomes possible to improve the power generation efficiency without any losses in the start-up time.

Further, since the temperature of the combustion gas is decreased, generation of waste heat is suppressed. Moreover, since the temperature of the oxygen-containing gas is increased, thermally self-sustaining operation is facilitated.

The combustion gas herein is a gas generated by the exhaust gas combustor **52** and the start-up combustor **54**. The combustion gas is a heating medium which can provide heat by performing heat exchange with a fluid to be heated (e.g., another gas). After heat energy is released from the combustion gas, the combustion gas is referred to as the exhaust gas. Further, thermally self-sustaining operation herein means operation where the entire amount of heat quantity required for operating the fuel cell system is supplied within the fuel cell system, and where the operating temperature of the fuel cell system **10** is maintained using only heat energy generated in the fuel cell system **10**, without supplying additional heat from the outside.

Further, in the fuel cell module **12**, the combustion gas channel **70** for supplying the combustion gas successively to the heat exchanger **50**, the reformer **46**, and the evaporator **48**, and the oxygen-containing gas channel **58** for supplying the oxygen-containing gas from the heat exchanger **50** to the fuel cell stack **24** are provided. The first thermoelectric converter **74** is provided downstream of the evaporator **48** in the combustion gas channel **70**, and provided upstream of the heat exchanger **50** in the oxygen-containing gas channel **58**.

Thus, the temperature difference between the combustion gas and the oxygen-containing gas, i.e., the heat energy can be collected as electrical energy without hindering thermally self-sustaining operation, and it becomes possible to improve the power generation efficiency. Further, since the temperature of the combustion gas is decreased, generation of waste heat is suppressed. Moreover, since the temperature of the oxygen-containing gas is increased, thermally self-sustaining operation is facilitated.

Further, in the fuel cell module **12**, the oxygen-containing gas channel **58** includes the cooling channel **104** for cooling the start-up combustor **54**, at a position upstream of the heat exchanger **50**, and the first thermoelectric converter **74** is provided upstream of the cooling channel **104**. Therefore, the oxygen-containing gas is supplied as the coolant for cooling the start-up combustor **54** before the oxygen-containing gas is supplied to the heat exchanger **50**.

In the structure, the temperature in the start-up combustor **54** can be kept at the self-ignition temperature of the fuel gas or less, and occurrence of back fire is suppressed. Thus, improvement in the durability of the start-up combustor **54** is achieved easily. Further, since the air (oxygen-containing gas) having a relatively low temperature is supplied to the first thermoelectric converter **74**, it is ensured that the there is a significant temperature difference between the air and the combustion gas. Thus, thermoelectric conversion can be performed efficiently.

Further, the second thermoelectric converter **106** is provided in the start-up combustor **54**. Thus, the temperature difference between the combustion gas and the oxygen-containing gas, i.e., the heat energy can be collected as electrical energy without hindering thermally self-sustaining operation, and it becomes possible to improve the power generation efficiency. Further, since the temperature of the combustion gas is decreased, generation of waste heat is suppressed. Moreover, since the temperature of the oxygen-containing gas is increased, thermally self-sustaining operation is facilitated.

In the first thermoelectric converter **74** (and the second thermoelectric converter **106**), the combustion gas flowing through the serpentine combustion gas channel **114***c* and the oxygen-containing gas flowing through the serpentine oxygen-containing gas channel **112***c* flow in parallel to each other, and the thermoelectric conversion elements **116***a*, **116***b*, and **116***c* each having a different thermoelectric conversion temperature are provided.

Therefore, as shown in FIG. **8**, on the upstream side of the parallel flow, since the temperature difference between the combustion gas and the oxygen-containing gas is large, the hot temperature type thermoelectric conversion element **116***a* is used. On the downstream side of the parallel flow since the temperature difference is small, the low temperature type thermoelectric conversion element **116***c* is used. In this manner, since the optimum thermoelectric conversion elements **116***a*, **116***b*, and **116***c* are used depending on the temperature difference, the efficient thermoelectric conversion can be performed reliably.

Further, the oxygen-containing gas channel **58** is branched into the first oxygen-containing gas supply channel **80***a* for supplying the oxygen-containing gas to the heat exchanger **50** and the second oxygen-containing gas supply channel **80***b* for supplying the oxygen-containing gas to the start-up combustor **54**. The oxygen-containing gas regulator valve **118** for regulating distribution of the oxygen-containing gas is provided at the branch portion.

In the system, temperatures of the fuel cell stack **24** and the FC peripheral equipment (BOP) **56** including the reformer **46**, the evaporator **48**, the heat exchanger **50**, and the exhaust gas combustor **52** can be increased at the same time, and thus, reduction in the start-up time is achieved.

Further, since precise temperature control is implemented for each of the fuel cell stack **24** and the FC peripheral equipment **56**, thermally self-sustaining operation of the fuel cell module **12** is facilitated. Moreover, if any heat shortage occurs in the fuel cell stack **24** or the FC peripheral equipment **56**, heat can be supplied from the start-up combustor **54**.

Further, in the fuel cell module **12**, the raw fuel channel **57** for supplying raw fuel to the reformer **46** is provided, and the raw fuel branch channel **110** is branched from the raw fuel channel **57** for supplying the raw fuel from the raw fuel channel **57** to the start-up combustor **54**, and at the branch portion, the raw fuel regulator valve **120** for regulating distribution of the raw fuel is provided. In the structure, temperatures of the fuel cell stack **24** and the FC peripheral equipment **56** can be increased at the same time, and reduction in the start-up time is achieved.

Further, since precise temperature control is implemented for each of the fuel cell stack **24** and the FC peripheral equipment **56**, thermally self-sustaining operation of the fuel cell module **12** is facilitated. Moreover, if any heat shortage occurs in the fuel cell stack **24** or the FC peripheral equipment **56**, heat can be supplied from the start-up combustor **54**.

Further, the exhaust gas combustor **52** is provided integrally in the heat exchanger **50**. The start-up combustor **54** is provided adjacent to one end of the heat exchanger **50** and the reformer **46** is provided adjacent to the other end of the heat exchanger **50**. In the structure, the reformer **46**, the heat exchanger **50**, the exhaust gas combustor **52**, and the start-up combustor **54** are substantially combined together. Therefore, heat radiation from the fuel cell module **12** can be minimized as much as possible. Accordingly, losses in the heat energy are suppressed, and thermally self-sustaining operation is suitably facilitated. Further, combustion circuits (e.g., pipes) are simplified, and the number of components is reduced. Thus, reduction in size and cost is achieved.

Further, the fuel cell module **12** is a solid oxide fuel cell module. Therefore, the fuel cell module **12** is applicable to high temperature type fuel cells such as SOFC.

FIG. **10** is an exploded perspective view showing main components of a thermoelectric converter **130** of a fuel cell module according to a second embodiment of the present invention.

The thermoelectric converter **130** is used instead of the first thermoelectric converter **74** and the second thermoelectric converter **106** of the fuel cell module **12** according to the first embodiment of the present invention. It should be noted that the thermoelectric converter **130** may be used only instead of the first thermoelectric converter **74** or used only instead of the second thermoelectric converter **106**. Likewise, the thermoelectric converter as described later in third and fourth embodiments may be used only instead of the first thermoelectric converter **74** or used only instead of the second thermoelectric converter **106**.

The thermoelectric converter **130** includes a first channel member **132** as a passage of the oxygen-containing gas, a second channel member **134** as a passage of the combustion gas, and a plurality of thermoelectric conversion elements **136** provided between the first channel member **132** and the second channel member **134**. The thermoelectric conversion elements **136** have a predetermined thermoelectric conversion temperature.

The first channel member **132** includes a serpentine oxygen-containing gas channel **132***c* extending in a serpentine pattern between an oxygen-containing gas inlet **132***a* and an oxygen-containing gas outlet **132***b*. The serpentine oxygen-containing gas channel **132***c* is formed by partition plates **132***d* provided alternately in a zigzag pattern in the first channel member **132**.

The second channel member **134** includes a serpentine combustion gas channel **134***c* extending in a serpentine pattern between a combustion gas inlet **134***a* and a combustion gas outlet **134***b*. The serpentine combustion gas channel **134***c* is formed by partition plates **134***d* provided alternately in a zigzag pattern in the second channel member **134**. The combustion gas in the serpentine combustion gas channel **134***c* and the oxygen-containing gas in the serpentine oxygen-containing gas channel **132***c* flow in a counterflow manner.

In the second embodiment, in the thermoelectric converter **130**, the combustion gas and the oxygen-containing gas flow in a counterflow manner. The thermoelectric converter **130** includes the plurality of thermoelectric conversion elements **136** having a predetermined thermoelectric conversion temperature. In the structure, in the thermoelectric converter **130**, the thermoelectric conversion elements **136** having the optimum thermoelectric conversion temperature can be used depending on the expected temperature difference. Thus, efficient thermoelectric conversion can be performed reliably.

FIG. **11** is an exploded perspective view showing main components of a thermoelectric converter **140** of a fuel cell module according to a third embodiment of the present invention.

The thermoelectric converter **140** includes a first channel member **142** as a passage of the oxygen-containing gas, a second channel member **144** as a passage of the combustion gas, and a plurality of thermoelectric conversion elements **146** provided between the first channel member **142** and the second channel member **144**. The thermoelectric conversion elements **146** have a predetermined thermoelectric conversion temperature.

The first channel member **142** includes a serpentine oxygen-containing gas channel **142***c* extending in a serpentine pattern between an oxygen-containing gas inlet **142***a* and an oxygen-containing gas outlet **142***b*. The serpentine oxygen-containing gas channel **142***c* is formed by partition plates **142***d* provided alternately in a zigzag pattern in the first channel member **142**.

The second channel member **144** includes a serpentine combustion gas channel **144***c* extending in a serpentine pattern between a combustion gas inlet **144***a* and a combustion gas outlet **144***b*. The serpentine combustion gas channel **144***c* is formed by partition plates **144***d* provided alternately in a zigzag pattern in the second channel member **144**. The combustion gas in the serpentine combustion gas channel **144***c* and the oxygen-containing gas in the serpentine oxygen-containing gas channel **142***c* flow in a manner that the combustion gas and the oxygen-containing gas intersect with each other.

In the third embodiment, in the thermoelectric converter **140**, the combustion gas and the oxygen-containing gas flow in a manner that the combustion gas and the oxygen-containing gas intersect with each other. The thermoelectric converter **140** includes a plurality of the thermoelectric conversion elements **146** having a predetermined thermoelectric conversion temperature. In the structure, in the thermoelectric converter **140**, the thermoelectric conversion elements **146** having the optimum thermoelectric conversion temperature can be used depending on the expected temperature difference. Thus, efficient thermoelectric conversion can be performed reliably.

FIG. **12** is an exploded perspective view showing main components of a thermoelectric converter **150** of a fuel cell module according to a fourth embodiment of the present invention.

The thermoelectric converter **150** includes a first channel member **152** as a passage of the oxygen-containing gas, a second channel member **154** as a passage of the combustion gas, and a plurality of thermoelectric conversion elements **156** provided between the first channel member **152** and the second channel member **154**. The thermoelectric conversion elements **156** have a predetermined thermoelectric conversion temperature.

The first channel member **152** includes a serpentine oxygen-containing gas channel **152***c* extending in a serpentine pattern between an oxygen-containing gas inlet **152***a* and an oxygen-containing gas outlet **152***b*. The serpentine oxygen-containing gas channel **152***c* is formed by partition plates **152***d* provided alternately in a zigzag pattern in the first channel member **152**.

The second channel member **154** includes a serpentine combustion gas channel **154***c* extending in a serpentine pattern between a combustion gas inlet **154***a* and a combustion gas outlet **154***b*. The serpentine combustion gas channel **154***c* is formed by partition plates **154***d* provided alternately in a zigzag pattern in the second channel member **154**. The combustion gas in the serpentine combustion gas channel **154***c* and the oxygen-containing gas in the serpentine oxygen-containing gas channel **152***c* flow symmetrically with each other.

In the fourth embodiment, in the thermoelectric converter **150**, the combustion gas and the oxygen-containing gas flow symmetrically with each other. The thermoelectric converter **150** includes the plurality of thermoelectric conversion elements **156** having a predetermined thermoelectric conversion temperature. In the structure, in the thermoelectric converter **150**, the thermoelectric conversion elements **156** having the optimum thermoelectric conversion temperature can be used depending on the expected temperature difference. Thus, efficient thermoelectric conversion can be performed reliably.

Although certain embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made to the embodiments without departing from the scope of the invention as set forth in the appended claims.

The invention claimed is:

1. A fuel cell module comprising:

a fuel cell stack for generating electricity by electrochemical reactions of a fuel gas and an oxygen-containing gas;

a reformer for reforming a mixed gas of water vapor and a raw fuel chiefly containing hydrocarbon to produce the fuel gas, and supplying the fuel gas to the fuel cell stack;

an evaporator for evaporating water, and supplying water vapor to the reformer;

a heat exchanger for raising a temperature of the oxygen-containing gas by heat exchange with a combustion gas, and supplying the oxygen-containing gas to the fuel cell stack;

an exhaust gas combustor for combusting the fuel gas discharged from the fuel cell stack as a fuel exhaust gas and the oxygen-containing gas discharged from the fuel cell stack as an oxygen-containing exhaust gas to produce a first portion of the combustion gas; and

a start-up combustor for combusting the raw fuel and the oxygen-containing gas to produce a second portion of the combustion gas,

wherein the fuel cell module includes a thermoelectric converter for performing thermoelectric conversion based on a temperature difference between the combustion gas and the oxygen-containing gas;

further comprising a combustion gas channel for supplying the combustion gas successively to the heat exchanger, the reformer, and the evaporator; and

an oxygen-containing gas channel for supplying the oxygen-containing gas from the heat exchanger to the fuel cell stack,

wherein the thermoelectric converter is provided downstream of the evaporator in the combustion gas channel, and upstream of the heat exchanger in the oxygen-containing gas channel.

2. The fuel cell module according to claim **1**, wherein the oxygen-containing gas channel includes a cooling channel for cooling the start-up combustor at a position upstream of the heat exchanger; and

the thermoelectric converter is provided upstream of the cooling channel.

3. The fuel cell module according to claim **2**, wherein another thermoelectric converter is provided in the start-up combustor.

4. The fuel cell module according to claim **1**, wherein the combustion gas and the oxygen-containing gas flow in the thermoelectric converter in parallel to each other, and the thermoelectric converter includes a plurality of thermoelectric conversion elements each having a different thermoelectric conversion temperature.

5. The fuel cell module according to claim **1**, wherein the combustion gas and the oxygen-containing gas flow in the thermoelectric converter in a counterflow manner, and the thermoelectric converter includes a plurality of thermoelectric conversion elements having a predetermined thermoelectric conversion temperature.

6. The fuel cell module according to claim **1**, wherein the combustion gas and the oxygen-containing gas flow in the thermoelectric converter in a manner that the combustion gas and the oxygen-containing gas intersect with each other, and the thermoelectric converter includes a plurality of thermoelectric conversion elements having a predetermined thermoelectric conversion temperature.

7. The fuel cell module according to claim **1**, wherein the combustion gas and the oxygen-containing gas flow in the thermoelectric converter symmetrically with each other, and the thermoelectric converter includes a plurality of thermoelectric conversion elements having a predetermined thermoelectric conversion temperature.

8. The fuel cell module according to claim **1**, wherein the oxygen-containing gas channel is branched into a first oxygen-containing gas supply channel for supplying the oxygen-containing gas to the heat exchanger and a second oxygen-containing gas supply channel for supplying the oxygen-containing gas to the start-up combustor; and

an oxygen-containing gas regulator valve for regulating a distribution amount of the oxygen-containing gas is provided at a branch portion.

9. The fuel cell module according to claim **1**, further comprising a raw fuel channel for supplying the raw fuel to the reformer,

wherein a raw fuel branch channel for supplying the raw fuel to the start-up combustor is branched from the raw fuel channel; and

a raw fuel regulator valve for regulating a distribution amount of the raw fuel is provided at the branch portion.

10. The fuel cell module according to claim **1**, wherein the exhaust gas combustor is provided integrally in the heat exchanger; and

the start-up combustor is provided adjacent to one end of the heat exchanger, and the reformer is provided adjacent to the other end of the heat exchanger.

11. The fuel cell module according to claim **1**, wherein the fuel cell module is a solid oxide fuel cell module.

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